

**IN THE CLAIMS:**

**Please amend Claims 2, 3, 5 and 8.**

**Please add Claims 14-15 as follows.**

1. (Amended) ~~A method for recovering 3D scene structure and camera motion from image data obtained from a multi-image sequence, wherein a reference image of the sequence is taken by a camera at a reference perspective and one or more successive images of the sequence are taken at one or more successive different perspectives by translating and/or rotating the camera, the method comprising the steps of: An image processing method for recovery of a scene structure and camera motion from successive image data, comprising:~~

(a) ~~comparing a determining image data shifts for each successive image with respect to the reference image to successive images, wherein the successive images are taken by translating or rotating the camera with respect to the reference image; the shifts being derived from the camera translation and/or rotation from the reference perspective to the successive different perspectives;~~

(b) ~~determining constructing a shift data matrix that incorporates the image data shifts for the successive each image with respect to the reference image;~~

(c) ~~constructing a shift data representation that incorporates the image data shifts for each image including a first data record calculating a rank-1 factorization from the shift data matrix using SVD, with one of the rank-1 factors being a vector corresponding to the 3D structure and a second data record corresponding the other rank-1 factor being a vector corresponding to the size of the camera motions;~~

(d) dividing the successive images into ~~smoothing~~ windows;

(e) determining ~~recovering~~ the direction of camera motion and ~~3D~~  
~~structure from the first and second data records between the windows, vector~~  
~~corresponding to the 3D structure by solving a linear equation; and~~

(f) ~~recovering the 3D structure by solving a linear equation using the~~  
~~recovered camera motion.~~

2. (Currently Amended) The method of claim 1, wherein, step (e) includes:

~~computing a first projection matrix matrices;~~

~~recovering camera rotation data records vectors and direction of camera~~  
~~translation from the shift data representation matrix, and the first projection matrices~~  
~~matrix;~~

~~computing a second projection matrix; and~~

~~recovering the direction of camera translation using the shift data matrix,~~  
~~the reference image, the second projection matrix and the recovered camera rotation~~  
~~vectors.~~

3. (Currently Amended) The method of claim 2, wherein step (f) (e) further includes  
recovering the 3D structure from the shift data ~~representation matrix, the reference image,~~  
the recovered camera rotation ~~data record~~ vectors and the recovered direction of  
translation ~~data record~~ vectors.

4. (Original) The method of claim 1, further including preliminary steps of:

recovering the rotations of the camera between each successive image; and

warping all images in the sequence toward the reference image, while neglecting the translations.

5. (Currently Amended) The method of claim 1, wherein step (b) comprises:

computing  $H$  and  $\Delta_{CH}$ , where  $H$  is a  $(N_p - 3) \times N_p$  matrix defined so that  $HH^T$  is the identity matrix and  $H$  annihilates the three vectors  $\Psi_x, \Psi_y, \Psi_z$  where the three vectors are computed from the reference image as

$\Psi_x \equiv \{\nabla I \cdot r^{(1)}(p)\}, \Psi_y \equiv \{\nabla I \cdot r^{(2)}(p)\}, \Psi_z \equiv \{\nabla I \cdot r^{(3)}(p)\}$  where

$r^{(1)}(x, y), r^{(2)}(x, y), r^{(3)}(x, y)$  are defined by  $[r^{(1)}, r^{(2)}, r^{(3)}] \equiv \begin{bmatrix} -xy \\ -(1+y^2) \\ xy \end{bmatrix}, \begin{bmatrix} 1+x^2 \\ xy \\ x \end{bmatrix}, \begin{bmatrix} -y \\ x \end{bmatrix}$

and  $\Delta$  is a shift data matrix, that gives the difference in intensities between each successive image and the reference image and is a  $(N_l - 1) \times N_p$  matrix with entries  $\Delta I_n^i$ , where  $\Delta I_n^i$  is the change in (smoothed) intensity with respect to the reference image, and with no smoothing  $\Delta I_n^i = I_n^i - I_n^0$ , where  $N_l$  is the number of images,  $N_p$  is the number of pixels, and where  $I^i$  denotes the  $i$ -th image, with  $i=0, 1, \dots, N_l - 1$ , and where  $I_n^i = I^i(p_n)$  denotes the image intensity at the  $n$ -th pixel position in  $I^i$ , where  $I^0$  is the reference image, where  $x$  and  $y$  are the image coordinates of the pixel position and  $p = (x, y)$  and where  $\Delta_{CH} \equiv C^{-\frac{1}{2}} \Delta H^T$  where  $C$  is a constant matrix with and where the notation  $\{V\}$  used to denote a vector with elements given by the  $V^a$ .

6. (Original) The method of claim 1, wherein step (c) comprises:

computing a rank-1 factorization of  $-\Delta_{CH} \approx M^{(1)}S^{(1)T}$  where  $M^{(1)}, S^{(1)}$  are vectors corresponding to the motion and structure respectively.

7. (Original) The method of claim 1, wherein step (c) comprises:

computing a rank-3 factorization of  $-\Delta_{CH} \approx \sum_{a=1}^3 M^{(a)}S^{(a)T}$  where  $M^{(a)}, S^{(a)T}$  are vectors corresponding to the motion and structure respectively;

setting  $Z_n^{-1}$  as constant within each window, where  $Z$  is the depth from the camera to a 3D scene along the cameras optical axis;

listing each of the pixels so that those in the  $k$ -th smoothing window have sequential indices  $n_k, (n_k+1), \dots, (n_{k+1} - 1)$ ;

computing a first projection matrix by computing a  $N_p \times N_p$  projection matrix  $P_\Omega$  which is block diagonal with zero entries between different smoothing windows, and which annihilates the vectors  $\{\nabla I \cdot p\}, \{I_x\}$  and  $\{I_y\}$  where  $\{\nabla I\}$  is a vector containing the gradient of the intensity at each pixel, and  $I_x$  and  $I_y$  are the gradients of the intensity in the reference image in the  $x$  and  $y$  directions;

recovering the three camera rotation vectors includes solving the following equations

$$P_\Omega (H^T S^{(a)} - \Psi w^{(a)}) = 0 \text{ for the 3-vector } w^{(a)};$$

computing a second projection matrix includes computing a  $N_p \times N_p$  projection matrix  $P_T^{(a)}$ , which is block diagonal with zero entries between different

smoothing windows and annihilates  $(H^T S^{(a)}) - \Psi_{W^{(a)}}$  where  $W^{(a)}$  is the vector recovered previously;

recovering the directions of camera translations by solving for the directions of translation  $\hat{T}^{(a)}$  via

$$P_{\hat{T}}^{(a)} \left( -\hat{T}_x^{(a)} \{I_x\} - \hat{T}_y^{(a)} \{I_y\} + \hat{T}_z^{(a)} \{p \cdot \nabla I\} \right) = 0 \text{ and;}$$

recovering  $Z_n$  via

$$(H^T S^{(a)})_n - [\Psi_{W^{(a)}}]_n = \tau^{(a)} \left( Z_n^{-1} \left( \hat{T}_z^{(a)} p_n - [\hat{T}^{(a)}]_2 \right) \cdot \nabla I_n \right) \text{ where } [\hat{T}^{(a)}]_2$$

represents  $\hat{T}_x^{(a)} \hat{T}_y^{(a)}$  the x and y component of the translation direction, and where  $\tau^{(a)}$  are constants.

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8. (Currently Amended) The method of claim 1, wherein step (d) comprises:

setting  $Z_n^{-1}$  as constant within each window, where  $Z$  is the depth from the camera to a 3D scene along the camera's optical axis;

listing each of the pixels so that those in the  $k$ -th smoothing window have sequential indices  $n_k, (n_k+1), \dots, (n_{k+1} - 1)$ .

9. (Original) The method of claim 2, wherein the step of computing a first projection matrix includes computing a  $N_p \times N_p$  projection matrix  $P_\Omega$  which is block diagonal with zero entries between different smoothing windows, and which annihilates the vectors  $\{\nabla I \cdot p\}, \{I_x\}$  and  $\{I_y\}$  where  $\{\nabla I\}$  is a vector containing the gradient of the intensity at each pixel, and  $I_x$  and  $I_y$  are the gradients of the intensity in the reference image in the  $x$  and  $y$  directions.

10. (Original) The method of claim 2, wherein the step of recovering camera rotation vectors includes solving the following equation

$$P_{\Omega}(H^T S^{(1)} - \Psi w) = 0 \text{ for the 3-vector } w.$$

11. (Original) The method of claim 9 wherein, the step of computing a second projection matrix includes computing a  $N_p \times N_p$  projection matrix  $P_T$ , which is block diagonal with zero entries between different smoothing windows and annihilates  $(H^T S^{(1)}) - \Psi w$  where  $w$  is the vector recovered previously.

12. (Original) The method of claim 2 wherein, the step of recovering the direction of camera translation includes solving for the direction of translation  $\hat{T}$  via

$$P_{\hat{T}}(-\hat{T}_x \{I_x\} - \hat{T}_y \{I_y\} + \hat{T}_z \{p \cdot \nabla I\}) = 0.$$

13. (Original) The method of claim 3 wherein, step (f) includes, recovering  $Z_n$  via

$(H^T S^{(1)})_n - [\Psi w]_n = Z_n^{-1} (\hat{T}_z p_n - |\hat{T}|_2) \cdot \nabla I_n$  where  $|\hat{T}|_2$  represents  $\hat{T}_x \hat{T}_y$  the x and y component of the translation direction.

14. (New) A computer-readable medium that includes instructions for recovering scene structure and camera motion direction from successive image data obtained from a multi-image sequence containing a reference image and one or more successive images, whereby said one or more successive images of the sequence are taken at one or more

successive different perspectives by translating and/or rotating the camera wherein said instructions, when executed by a processor, cause the processor to:

- a) compare a reference image to successive images, wherein the successive images is taken by translating or rotating the camera;
- b) determine the image data shift for the successive images with respect to the reference image;
- c) construct a shift data representation that incorporates the image data shifts for each image including a first data record corresponding to the 3D structure and a second data record corresponding to the camera motion;
- d) divide the successive images into windows;
- e) determine the direction of the camera motion and 3D structure from the first and second data record between the windows.

15. (New) A computer system for recovering scene structure and camera motion direction from image data obtained from a multi-image sequence containing a reference image and one or more successive images, whereby said one or more successive images of the sequence are taken at one or more successive different perspectives by translating and/or rotating the camera, comprising:

- a processor;
- a video source whose output is digitized into a pixel map by a digitizer, said output is sent in electronic form via a system bus for access by main memory;
- a display means;
- a user interaction means for selecting items on the display means;

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a storage device in communication with said processor, said storage device stores program code for programming said processor to perform a method comprising the steps of:

- (a) accessing stored digitized video by the processor from main memory;
- (b) determining the image data shift for the successive image with respect to the reference image;
- (c) constructing a shift data representation that incorporates the image data shifts for each image including a first data record corresponding to the 3D structure and a second data record corresponding to the camera motion;
- (d) dividing the successive images into windows;
- (e) determining the direction of the camera motion and 3D structure from the first and second data records between the windows.